THE BALANCE BETWEEN INORGANIC ACIDS AND BASES IN ANIMAL NUTRITION

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PREFACE.

In this bulletin we seek to show the bearing, upon practical animal nutrition, of the relationship between those mineral elements of our foodstuffs and of living animal tissues, which in the body give rise to inorganic acids, and the various means at the disposal of the animal for accomplishing protection from these acids through effecting their neutralization.

The formation of inorganic acids from the food and from the tissues in the animal body, and the necessity for their neutralization, are always present, and therefore students of the effects of food-stuffs upon growth and other proteid increase in animals, must consider this factor in determining the causes of the results produced.

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THE BALANCE BETWEEN INORGANIC ACIDS AND BASES IN ANIMAL NUTRITION.

BY E B FORBES.

INTRODUCTION.

The vital reactions taking place in the bodies of animals require that certain necessary conditions be maintained with unvarying constancy.

None of these conditions is of wider or deeper significance to these vital processes than the state of the liquids and tissues as regards acidity and alkalinity.

Nearly all of the mineral elements in the body contribute to one or the other side of this account and thus become involved in a great number of most important functions.

This balance between acid and alkaline mineral elements in animal bodies is constantly maintained in adjustment by a most intricate system of compensating agencies, so that, under normal conditions, the matter is perfectly accomplished without our conscious intervention.

But we do not always live under "normal" conditions. We have set up standards for both man and his animals which differ greatly from those to which they have been adapted, and we use as foods and feeding stuffs a great variety of artificial products with which it is possible to tax the adaptability of the animal quite beyond the limits of toleration.

Indeed we are each year becoming more and more independent of the environment to which, through long ages of selection, our physiological processes have come to be attuned.

This fact imposes upon us the obligation to seek an understanding of the physiology of nutrition in order that our increasing abilities to shape our own lives may not find us wanting in intelligence to use our capacities to the best possible advantage.

The practical bearing of this subject has to do with normal growth, especially of the bones of animals, and the prevention of malnutrition of the bones—a very common trouble in certain regions; with rickets and osteomalacia in both man and other animals; with osteoporosis in live stock; with "bran disease" or "miller's horse rickets" and with the quality of the bones in horses; with acidosis in infants—a very common and troublesome nutritional disturbance and with diabetes and fevers.

It has a direct bearing on the production of all proteid increase in animals and hence upon the profitability of stock-farming, but especially on the rearing of those animals which are fed most largely upon cereals, especially corn alone, namely, swine and poultry. It has also a less important though an interesting bearing on the feeding of carnivorous animals in captivity, since they do not thrive on a diet of meat alone.

PHYSIOLOGICAL BASIS.

The main facts in physiology regarding the acid and alkaline mineral elements are as follows:

There are in all foodstuffs and in the living tissues of animals, mineral elements in organic combination, which upon oxidation in the body, yield inorganic acids. The animal must be protected from these acids, which would produce profound disturbance of function if allowed to circulate throughout the body. To this end they are neutralized with substances possessing a basic reaction and then, in their neutral condition, are either excreted or used as nutrients.

In this connection we consider especially the acid-reacting elements, sulphur, phosphorus and chlorine and the alkali-reacting elements, sodium, potassium, calcium and magnesium. Iron is not considered, since it is either base or acid according to circumstances and enters into vital activities only in its organic combinations.

THE ACID MINERAL ELEMENTS.

Sulphur enters the body almost wholly in organic combination as a constituent of food-proteins. As these proteins are oxidized in the body most of the sulphur is burned to sulphuric acid and is excreted in the urine as inorganic sulphates.

According to Sherman[1] 80 to 85 percent of the urinary sulphur in the human being is in the form, mostly of inorganic, but partly of ethereal sulphates, the remaining 15 to 20 percent being found in less completely oxidized forms This latter portion is designated "neutral sulphur" and consists of derivatives of taurin from the bile, sulphocyanids from the saliva and a considerable number of other compounds, some known and others as yet not identified.

According to Neuberg and Grosser[2], in addition to the inorganic and ethereal sulphates and the neutral organic compounds of sulphur in the urine, there is also a basic fraction made up of salts of an organic sulphonium base.

In the body, sulphur is used as a constituent of all proteid increase and in the repair of proteid waste. A considerable part of the food-protein, however, is oxidized for the production of energy and its sulphur and phosphorus appear mostly as sulphates and phosphates, in the excreta. The constant waste which there is in the proteids of the living tissues, also contributes to the production of the sulphates and phosphates of the excreta.

Phosphorus enters the body in a great variety of conditions; as inorganic phosphates; as salts of various organic acids; as lecithins, that is, compounds of fat, phosphoric acid and a nitrogenous group; as phosphoproteins and as nucleoproteins.

The distribution of the phosphorus of the excretions between urine and feces is governed by the nature of the food.

In herbivora nearly all of the phosphorus is excreted in the feces. In carnivora almost all of the phosphorus is excreted in the urine; while in omnivora, man included, the distribution of the phosphorus between urine and feces, seems to depend largely on the calcium and magnesium contents of the ration. In man about two-thirds of the phosphorus usually leaves the body in the urine and about one-third in the feces, while an increase of the vegetables in the dietary and of the magnesium and calcium intake, will increase the proportion of the phosphorus leaving the body in combination with mineral bases, in the feces.

In the body, phosphorus serves a multiplicity of purposes, both structural and regulative, and is used both in organic and inorganic combinations.

The urinary phosphorus is chiefly in the form of di- and monohydrogen phosphates of sodium and potassium; less abundantly in the form of phosphates of calcium and magnesium. The phosphorus of the feces is also largely in the shape of phosphates. Phosphorus in various organic combinations also occurs in the feces, including nucleins and ether-soluble compounds.

Chlorine enters the body as chlorides and leaves it almost wholly in the urine, as chlorides. In the body it is used as chlorides and as hydrochloric acid in the gastric juice, principally for regulative and digestive purposes.

THE BASIC MINERAL ELEMENTS.

The mineral bases, calcium, magnesium, sodium and potassium, enter the body mostly as salts of various organic and inorganic acids; though calcium, at least in milk, egg-yolk and seeds, occurs also in organic combination with proteins.

These alkali-reacting elements are used in the body mostly in inorganic combination with phosphoric, sulphuric, hydrochloric and carbonic acids, principally for structural, regulative and catalytic purposes. They leave the body as inorganic salts in combination with the above-mentioned mineral acids.

Thus it is seen that these mineral elements, both acid and basic, enter the body in a great diversity of forms, both organic and inorganic, perform in the body a multiplicity of complicated functions and then leave the body mostly in an inorganic condition.

ACIDOSIS.

Causes. When oxidizable organic compounds, either nitrogenous or acid, containing sulphur or phosphorus, are disintegrated, or when chlorides are decomposed in the animal body, there are formed, from the sulphur, phosphorus and chlorine, the corresponding non-oxidizable inorganic acids. Since these acids cannot be broken up by oxidation and excreted by the lungs, they possess a different significance from oxidizable organic acids. An excess of these or other mineral acids, or of non-oxidizable organic acids, in the body, gives rise to a pathological condition known as acid intoxication or acidosis. Acidosis is a name first used by Naunyn[16] to designate the excess of oxybutyric acid present in the blood in *diabetes mellitus*. It is, however, used to designate intoxication from other acids, either produced within the organism or introduced from without. In the use of this term the idea to be conveyed is that of an *excess* of acid. This may be brought about by the introduction or formation of abnormal amounts of acid, the bases not increasing in the same ratio, in which case the acidosis is said to be "absolute" (Naunyn), or it may be caused by a withdrawal from the body, of alkalis, the acids predominating merely because of this withdrawal of alkali, which type of acidosis was designated as "relative acidosis" by Steinitz.

The existence of acidosis is to be inferred from the excretion, by the kidneys, of an increased proportion of the nitrogen of the urine in the condition of ammonium salts, since ammonia is largely used by the animal to neutralize non-oxidizable acids.

In human pathology acidosis of the first type is most commonly caused by oxybutyric acid. In certain liver diseases lactic acid is also present in considerable quantities and uric, oxalic and aromatic acids may also contribute to its causation.

Diabetic coma or stupor is the result of acidosis, caused by a flooding of the tissues with oxybutyric acid and the related acetic acid. These acids are represented in the urine of healthy human beings by acetone, which may be formed from acetic acid by the splitting off of carbon dioxide.

Stadelman[3] first proved that diabetic coma was caused by an increased formation of these acids and that they were excreted by the kidneys in combination with ammonia.

These acids are formed in the body from fats (Magnus-Levy[17]) and their formation is caused by lack of carbohydrate (Hirschfeld[18]) in the diet, or by derangement of the carbohydrate metabolism, as in diabetes.

Oxalic acid, which is difficultly oxidizable, may also contribute to the causation of acidosis in human beings. It is introduced into the body in foods of vegetable origin and is to some extent formed in the body itself.

Acidosis of the second, or relative type, is caused principally by the sulphuric and phosphoric acids normally produced in the body by the cleavage and oxidation of proteids, either of foods or tissues, containing sulphur and phosphorus as constituent parts.

The formation, from fatty acids and alkalis in the intestine, of soaps, which because either of difficult solubility or of digestive disturbance are passed off in the feces instead of being resorbed, is a prominent factor in the production of the second type, or relative acidosis, particularly in infants suffering from digestive disorders.

The essential cause of acidosis is a disturbance by acids, of the reaction of the blood. Henderson[4] regards both blood and protoplasm to be characterized by "a very faint preponderance of alkalinity."

Neutrality of blood. The cause of this approximate neutrality is, according to Henderson, largely the result of a physico-chemical equilibrium between the carbonic acid, sodium bicarbonate, mono-sodium phosphate and di-sodium phosphate contained therein and maintained by secretory capacity of the lungs and kidneys.

Henderson explains the existence of this equilibrium as follows:

"In protoplasm phosphates are present in very great amount, undoubtedly as mixtures of mono- and di-potassium phosphates and similar salts; such mixtures constitute a nearly neutral solution which has the remarkable property of being able to take up large quantities of acid or alkali without becoming acid or alkaline. This behavior is easily explained by the facts that acid sufficient to convert all the di-potassium phosphate of such a mixture into mono-potassium phosphate must be added before the slight acidity of mono-potassium phosphate is obtained, and that enough alkali to convert all the acid potassium phosphate into di-potassium phosphate must be added before the faint alkaline reaction of the latter substance is obtained, while, in accordance with the requirements of the concentration law, all mixtures of the two substances are much more nearly neutral than either alone."

Symptoms of acidosis. The symptoms of acute acidosis are "air hunger," rapidity of the pulse, depression, stupor and deep coma. These symptoms seem to result from diminished oxidation, due to an accumulation of carbon dioxide in the tissues. This is caused by the diminished alkalinity of the blood, which results in its inability to transport carbon dioxide to the lungs.

The most important effects of a deficiency of mineral bases or an excess of mineral acids in the body are not made apparent by the above-mentioned acute symptoms. Of vastly greater importance must be the less noticeable influence of slightly unbalanced rations upon the development and general health of animals, when these influences remain operative during long periods of time. Little that is definite is as yet known regarding these effects. We feel safe in assuming, however, since acute malnutrition of the bones may be so readily caused in a few weeks by irrational nutrition, that a slight departure from the optimum relationship of bases to acids in the food, if persisted in during the whole of the growing period, can not be without serious consequences in the development of the skeleton.

Indeed, it is a matter of common knowledge that prevailing methods of feeding of swine in the Corn Belt result in just such a gradual moulding of the style of growth as the animal develops, and this at least partially on account of the acid ash of corn.

After so much has been said about excess of mineral acid in the animal body, a fair question would be: "What about mineral bases? Would not an excess of alkali be equally dangerous?" So it might be, but the body has apparently an entirely adequate method of disposition of alkalis so that injurious excess does not occur. Volatile alkali (ammonia) is excreted in salts of mineral or organic acids, or as urea and fixed alkali (sodium and potassium) and alkaline earths (calcium and magnesium), as salts either of acids such as sulphuric, phosphoric, hydrochloric or carbonic acid, or of certain organic acids.

The neutralization of acids. A very slight disturbance by acids of the reaction of the blood must result in a complete disappearance from it of carbon dioxide. Thus it becomes a matter of much importance to the animal that the neutrality or slight alkalinity of the blood be abundantly safeguarded.

In herbivora this is accomplished by the formation of carbonates, in the body, by oxidation of the abundant organic-acid-salts of sodium, potassium, calcium and magnesium which are found in vegetable foods, and under ordinary circumstances the carbonates thus formed are quite sufficient to meet the requirements of the animal. In this class of animals there is but very slight provision for any other method of neutralization of acids.

Because of the practical inability of herbivora to neutralize acids with ammonia and the limited capacity of carnivora and omnivora to do the same, there comes a time, with increased consumption or production of non-oxidizable acids, and much more quickly with herbivora than with omnivora and carnivora, when the animal is no longer able to maintain the neutrality of its blood and tissues. At this point acute symptoms of acid intoxication, or acidosis, as it is called, appear and death may follow quickly with symptoms of asphyxia.

Omnivora and carnivora consume comparatively little mineral base in combination with organic acid and also comparatively little preformed carbonates. Further than this, their food, being much richer in protein than the food of the herbivora, produces correspondingly greater amounts of sulphuric and phosphoric acids by its cleavage and oxidation within the body. Hence we see that there is necessity for the provision of an extensive acid-neutralizing function in these animals. In accord with this requirement we find that carnivora and omnivora have the capacity to neutralize a certain amount of acid in the body with ammonia. This use of ammonia for acid-neutralization does not increase in extent proportionately with increase in the consumption of protein, however; otherwise there would be no such thing as acidosis from an exclusive protein diet, the fact of the existence of which is abundantly demonstrated.

This ammonia which is used for acid-neutralization has its origin in three distinct processes.

(1) Ammonia is produced in the digestive tract in considerable quantities, and by way of the portal vein and other channels reaches the other tissues of the body. It is also formed in all the organs of the body and by them is contributed, possibly as the carbamate, to the blood. According to Magnus-Levy[5] the process of splitting off ammonia from protein is widely prevalent and generally, or often,

precedes the oxidation of the carbon-containing residue. Thus we may consider ammonia as a normal product of the disintegration of protein and its universal presence in the tissues as affording a slight store of alkali available for acid-neutralization.

(2) A second fraction may be considered to be split off from proteids especially for the purpose of acid-neutralization. Thus Folin[8] says: "In the study of ammonia as a product of metabolism,* it must be remembered that this substance is a base, and its formation in the animal organism is therefore probably quantitatively determined by the necessity of forming salts." Magnus-Levy[7] with the same idea in mind says: "As soon as the amount of acid produced exceeds the amount necessary to neutralize the stored-up ammonia or other alkali, autolysis† sets in, and nitrogenous equilibrium ceases to be maintained."

"In well nourished animals there is always an excess of ammonia present which gradually disappears as the animal is deprived of food. A certain stage will then be reached when the production of acid exceeds the amount of ammonia available for neutralization; the autolytic enzyme them comes into play, liberates amino-acids, etc., which in their turn pass to the alimentary tract, and by means of the metabolic processes taking place then liberate ammonia, which again inhibits the production of nitrogenous degradation products." This second fraction then, may be considered to represent a purposive adjustment.

(3) The third source of ammonia available for acid-neutralization is of much greater importance, quantitatively, than the two above-mentioned. This fraction becomes available through its withdrawal from urea formation in the liver.

In mammals, very much the greater part, about 80 percent, of the nitrogen leaving the body, reaches the kidneys as urea. It is formed chiefly in the liver, though also to slight extent in other organs, and chiefly by synthesis, or constructive reaction, from ammonium compounds, possibly from the carbamate or the carbonate, though probably also formed to some extent (Drechsel[9]) directly from certain proteids by a simple splitting or cleavage of the compound, with the taking up of water, and thus without synthesis or constructive change.

* Metabolism is chemical change due to the processes of life.

† Autolysis is that type of chemical change from complex to simpler compounds which is exemplified in the ripening of beef and cheese. Such changes are produced through the agency of a group of chemical compounds which are universally present in plant and animal tissues and which are known as enzymes.

This formation of urea in the liver, from ammonium compounds, may be spoken of as for the purpose of affording the body protection from ammonia. Thus we may consider that the ammonia in the body, available for purposes of acid-neutralization, comes (1) from the tissues, (2) from body proteids and (3) by withdrawal from urea formation.

The nitrogen of the urine may be caused to appear therein almost wholly as ammonium salts by the administration of mineral acids. Conversely the nitrogen of the urine may, by the administration of alkali carbonates, be caused to appear in the form of urea, with a great reduction in the amount of ammonium salts present.

Walther[10] first proved, with dogs, that after administering hydrochloric acid, there was a marked increase in the ammonium salts of the urine, about three-fourths of the hydrochloric acid being excreted in this form.

Organic acids, in general, cause no increase in the excretion of nitrogen as ammonium salts since they are, as a rule, oxidized to carbon dioxide and water and are excreted in these compounds; benzoic and certain related acids, however, are not oxidized, and oxybutyric, acetic and lactic acids may be, like the mineral acids, excreted in combination with ammonia.

Now, have we right to consider that neutralization of acids by ammonia affords the animal as complete protection as their neutralization by fixed alkalis or alkaline earths?

Voegtlin and King[11] suggest that the ammonium salts themselves may play "an important role in producing the symptoms of these diseases." Intravenous injections of ammonium salts of lactic, hydrochloric and beta-oxybutyric acids produced symptoms of acid intoxication, while intravenous injections of calcium salts completely antagonized the toxic action of the ammonium salts.

According to A. P. Mathews[50] ammonium salts in solution decompose, not only into the ammonium and acid groups but also, to a certain extent, with the taking up of water, into ammonium hydroxide and the free acid. These decompositions may subject the animal to the action of ammonia, as stated by Mathews, and of the acid involved, as implied by Voegtlin and King. Thus we may consider it at least a possibility that neutralization of acids by ammonia does not afford an animal complete protection from these acids.

A second source of acid-neutralizing material in all animals is the calcium salts of the bones and other tissues. Where a ration characterized by a deficiency of mineral bases is fed during a considerable period of time, as for instance, in feeding corn to swine, (see experiments by the author[12]), the withdrawal of mineral matter from the bones and the prevention of its deposit within them, may affect not only the size and strength of the bones, but the size and general style of development of the animal.

That the calcium of the blood may also be used for acid-neutralization is indicated by the fact of the great variability of the content of blood in this element. According to Albu and Neuberg[13], Bunge found .04 percent of calcium, reckoned as the oxide, while Demstedt and Rumpf found values up to .27 percent. That the calcium content of the blood depends upon the food was proven by Hirschler and Terray who found it varying between .0023-.0051 percent (CaO) in accordance with the food.

Rey[19] also has demonstrated with dogs a very considerable retention of calcium in the blood for some days and Weiske in his experiments with rabbits has, by feeding calcium carbonate with oats, shown an apparent increase in the calcium carbonate in the ash of the bones from 5.5 and 6.2 percent to 7.6 and 8.4 percent.

According to Albu and Neuberg[15], Rüdel found with dogs, after the administration of hydrochloric acid, an increase to twice the quantity, and Gäthjens, after the administration of sulphuric acid, three times the quantity of calcium in the urine; and Caspari, after giving oxalic acid, as much as ten times the normal average. Rumpf saw an increase of 50 percent in the calcium excretion in men, after the administration of lactic acid and sodium lactate.

O. Wellmann[20] found that the calcium and phosphorus excreted from the body during fasting comes from bone substance and S. W. Patterson[21], in experiments with rabbits fed on oatmeal and corn-meal, that the deficiency of these foods in calcium results in a loss of calcium from the bones.

Thus in considering this matter of balance between mineral acid and mineral base in animal nutrition, we must think of the acids as produced (1) by the destruction or katabolism of the body proteids, (2) by the oxidation of food proteids, and (3) to a slight extent by the decomposition of sodium chloride in the formation of gastric juice.

On the other hand we must consider the bases available for their neutralization as contributed principally (1) by the carbonates formed from alkali salts of organic acids in the food, (2) by the withdrawal of ammonia from the formation of urea in the liver, (3) by ammonia split off from body proteids, for the purpose of acid-neutralization, (4) by carbonates and ammonia of the tissues and (5) by the decomposition of sodium chloride in the formation of gastric juice.

Effects of acidosis. The first substantial progress toward an understanding of acidosis was due to the studies of Forster, Bunge and Lunin.

Forster[22] fed dogs and pigeons on practically ash-free food. They succumbed in a very few days. He considered the lack of mineral matter to be the cause of death.

Bunge[23] however, suggested that the fatal termination of the experiment might be due to sulphuric acid produced by the oxidation of protein.

Lunin[24] put this idea to a test by feeding mice on an ash-free diet, with and without sodium carbonate. With the sodium carbonate the mice lived twice as long as without it, because this salt neutralized the acids produced by the oxidation of proteids.

Kemmerich[25] found it impossible to maintain young dogs on meat-scrap from which the minerals had been extracted.

Salkowski[26] and Walter[27] found that the administration of hydrochloric acid to rabbits and dogs resulted in a withdrawal from their bodies of the fixed alkalis, and in death.

Salkowski first learned that acids produced in destructive or katabolic processes of human beings, of carnivora and of herbivora may be excreted united with mineral bases.

Effects of diet of meat. Chalmers Watson[28] has found that in animals fed on an exclusive meat diet the bones present an appearance of delayed and imperfect ossification with increased vascularity, or blood content, and an increase in the number of red blood-corpuscles. The symptoms are very similar to those in rickets in human beings, but microscopic examination shows that they are not identical.

D. Forysth[29] however, fed domestic fowls for periods varying from 11 months to 2 years upon meat, supplemented by lime. The animals remained healthy and their bones normal.

E. J. Spriggs[30] found that rats when fed on meat alone had rough and abnormal coats, but that when lime was added to the diet the appearance of the coat was nearly normal.

Effects of diet of cereals. Weiske[31] found that exclusive oat feeding to young rabbits resulted in a very marked demineralization of the skeleton generally, but not of the teeth. His observations regarding the teeth are, he says, in accord with those of H. Beraz (Zeitschr. f. Biol. Vol. 17, p. 386.)

While the dry, fat-free weight of the skeleton decreased, that of the teeth increased during the feeding of oats, with calcium sulphate in one case and tricalcic phosphate in another.

It is of interest to note that the administration of calcium phosphate with the oats did not prevent a loss in the dry, fat-free weight of the skeleton.

Weiske has also shown, by administering dilute sulphuric acid or monosodium phosphate in the food, to rabbits and sheep, that the percentage of ash in the bones could be decreased. By continuous feeding of cereals, for protracted periods, to mature herbivora, he also produced demineralization of the skeleton.

In unpublished experiments by the author, with swine, in the comparison of the nutritive values of various compounds of phosphorus, malnutrition of the bones has been caused by insufficiency of mineral bases to neutralize the mineral acids present. A low-phosphorus basal ration, supplemented with hypophosphites, produced acute disturbance of nutrition, as shown by great lameness, stupor, excessive fatness, minimum increase in weight of muscles, maximum percentage of fat in the increase, decided loss in breaking strength and in ash per cubic centimeter and in total weight of ash of the bones. This ration produced knob-like swellings at the point of union between the ribs and their cartilaginous extensions and required modification in order to keep the pigs alive for fifty-six days.

The same basal ration, supplemented by glycerophosphates of the same mineral bases, produced great increase in the size, breaking strength and total ash in the bones and also in the ash per cubic centimeter of bones. There was also a maximum increase in the weight of the muscles and a minimum percentage of fat in the increased weight, and the pigs throve exceedingly. These differences, in so far as they relate to the bones, are due largely to the greater proportion of acid to base in hypophosphites than in glycerophosphates; and as they relate to muscular development, are due to the fact that glycerophosphates are useful in muscular growth, while hypophosphites will not sustain development of these tissues.

In earlier work the author found that water-extract of wheat bran, which contains an abundance of phosphorus as calcium-magnesium-potassium-phytate, had the capacity greatly to strengthen the bones of pigs and to contribute to the growth both of bones and muscles, but when this food was used in excess it caused, probably through an excess of acid mineral elements contributed to the ration, pathological symptoms and much less increase in the growth of bone and muscle.

"Bran disease," "shorts disease" or "miller's horse rickets" is in all probability malnutrition of the bones, possibly combined with acidosis, due to lack of calcium in the food, and perhaps to a superabundance of acid mineral elements; possibly also to an excess of magnesium.

It is very well known by all intelligent swine-breeders that corn alone does not produce maximum growth of bone. The fact has also been proven, many times over, by a large number of experimenters in the field of animal husbandry, especially by Henry, of Wisconsin, and by thousands of stock-raisers in every-day practice, that the addition of mineral matter, either in other foods or by itself as in wood-ashes or bone-meal, is beneficial to bone formation and also, to some extent, to structural development generally.

This deficiency of corn in mineral matter is due to a lack of mineral bases generally and to lack of calcium especially, and probably also to a lack of phosphorus. It is possible that unfavorable effects are also due to an excessive proportion of magnesium in relation to calcium. In bone there is 86 times as much calcium as magnesium and in the body generally about 40 times as much, while in corn there is ten times as much magnesium as calcium. Certain evidence lends support to the idea that this disproportion of calcium to magnesium in corn may be a matter of importance. In our experiments corn alone has produced weak bone and little muscle, while the addition of protein and mineral matter, in the shape either of organic or inorganic phosphates, has proven quite effective to cause increased capacity to produce bone and muscles. Feeding on corn alone often results in the "breaking down" of fat hogs on the way to market and of brood sows upon the farm. Show hogs often exhibit symptoms of a similar weakening of the tendinous attachments when "let down" too rapidly after the show season and hogs being fitted for show are often "fed off their feet," as the saying goes, by crowding them along too fast on foods which contain a deficiency of mineral bases (especially calcium) in relation to the acid mineral elements present.

MALNUTRITION OF THE BONES.

These above cases of malnutrition of the bones are the results of two factors, (1) lack of bone-forming constituents and (2) an excess, either absolute or relative to mineral bases, of acid mineral elements.

These same factors receive consideration as contributory causes of osteomalacia, rickets and osteoporosis, diseases in which malnutrition of the bones is a prominent symptom, though malnutrition is by no means the sole cause of these difficulties.

Rickets and osteomalacia are diseases involving various tissues; among others, the bones. In rickets demineralization occurs through a loss of capacity, by the bone-forming tissue, of the power of absorbing and assimilating calcium. In osteomalacia there is a loss of the power of the bones to retain calcium. The cause of neither disease, as it occurs in human beings, is known. While these diseases often follow deficiency of the food in calcium and phosphorus, this is by no means the only cause and in human beings, at least, apparently not the fundamental one, especially in rickets.

Osteomalacia. In osteomalacia it appears that the carbonates are not removed from bone more rapidly than the phosphates.

Magnus-Levy[32] found in the bones of a woman who had died from osteomalacia that the calcium and phosphorus decreased in the same ratio, one to another, as that in which they occur in normal bone. In treating fresh, normal bone with lactic acid, much more of the carbonate dissolves out than of the phosphate.

Mohr[33] says regarding metabolism in osteomalacia, "It is an important fact that the loss of mineral matter affects all the constituent elements equally and not the calcium especially."

Thus it is apparent that the loss of mineral matter from the bones in osteomalacia is directly due to autolysis and not to solution in free acids.

Veterinary writers usually say without qualification that osteomalacia is caused by lack of mineral salts in the food. Thus Atkinson and Mohler[35] say, "The cause of this affection is the insufficiency or total absence of lime salts in the food, also to feeding hay of low, damp pastures, kitchen slops and potatoes, or to overstocking lands. It occurs on old, worn-out soil, devoid of lime salts, and has been observed to follow a dry season. The disease in this country is confined to localized areas in the Southwest, known as the "alkali districts," and to the old dairy sections of New York."

In the 15th Annual Report of the Bureau of Animal Industry, 1898, p. 530, osteomalacia is reported as common in Texas, especially in dry summers. The cause is here stated to be an insufficient supply of certain mineral ingredients in the food, probably phosphates of lime.

Law[36] speaks of the prevalence of the disease in damp lowlands of Belgium and Jutland, in the Swiss valleys, on the damp lands of New Jersey and the Carolina seaboard, and generally on damp pastures with rank, watery herbage.

A large number of agriculturists and veterinarians, in Europe and in South Africa, also believe that the cause of osteomalacia is a deficiency of the herbage in calcium and phosphorus, either because of natural poverty of the soils in these elements, as in parts of South Africa, and in certain regions in the Hawaiian Islands, or because of abnormally low calcium and phosphorus contents of the forage on worn lands, following a dry season.

The above ideas as to causes of osteomalacia in live-stock are easily harmonized.

In dry seasons the minerals in the forage are deficient because of diminished transpiration of water. In dry regions we have the same condition present. Scanty food, due either to drought or to over-stocking of the pasture, also limits the amount of mineral nutrients available to the animal. On soils naturally deficient in lime or phosphorus, or on those depleted by tillage, the forage is low in these elements. On abnormally damp pastures or poor lands a low mineral intake might be explained simply by the bulky character of the watery grass. Then too its laxative character would interfere with the utilization of its nutrient constituents. The author has seen chinch bugs thrive exceedingly in an insectary on scantily watered corn, while they drank themselves to death on the dilute sap of generously watered plants. Animals most likely to suffer from osteomalacia are colts, cows with the first calf and heavily producing milk cows.

The symptoms, according to Atkinson and Mohler[35], are "a gradual emaciation and symptoms of gastro-intestinal catarrh, with depraved appetite, the animal eating manure, decayed wood, dirt, leather, etc. Muscular weakness is prominent, together with muscle tremors, which simulate chills, but are not accompanied by any rise of temperature. The animal has a stiff, laborious gait; there is pain and swelling of the joints, and constant shifting of the weight from one leg to another. The restricted movements of the joints are frequently accompanied by a crackling sound, which has caused the name of "creeps" to be applied to the disease. The coat is dull and rough and the skin dry and hidebound. The animal is subject to frequent sprains or fracture of bones without apparent cause, as in lying down or turning around, and when such fractures occur they are difficult to unite. The bones principally involved are the upper bones of the legs, the haunch bone, and the middle bones of the spinal column."

Friedberger and Fröhner[37] consider that, in live stock, there is a close relationship between osteomalacia and rickets and speak of rachitis as "a form of osteomalacia due to special conditions of growth of the young bone."

They consider an insufficient quantity of calcium in the food, either from deficiency of the soil in calcium, or from climatic influence, to be a cause of this disease.

Bran disease of horses they describe as but a form of rickets and also say that in old animals it is identical with osteomalacia.

In this disease there are bony enlargements about the articulations of the knees and tarsus and changes appear in the bones of the head, including loss of the teeth. The disease may result fatally.

Friedberger and Fröhner speak of rickets as being especially common in young pigs and dogs and state that its dominating cause is want of calcareous salts in the food.

Prominent among the anatomical symptoms are congestion and thickening of the periosteum; the bone becomes covered with exostoses, especially at points of muscular attachment; muscular contractions may remove the thickened periosteum; profound changes also occur at the ends of the long bones which result in abnormal growth of the cartilage and in various deformities. In livestock this disease responds readily to treatment with calcium phosphate, which may be supplied mixed with salt. A change of ration to one containing an abundance of calcium is also of decided benefit.

Osteoporosis. This disease appears to be distinct from osteomalacia. Its cause is unknown. It does not respond to medication with calcium phosphate and is not caused by deficiency of the food in calcium and phosphorus, though this may be a contributory cause.

Mohler[38] says of this disease: "In the southwest, where osteomalacia or "creeps" has not infrequently been observed by the writer among range cattle, no case of osteoporosis of the horses using the same range has been noted, although the latter are given no more care or attention than the cattle."

"Osteoporosis is a general disease of the bones which develops slowly and progressively and is characterized by the absorption of the calcareous or compact bony substance and the formation of enlarged, softened and porous bone. This fragile and deformed condition is particularly manifest in the bones of the head, causing enlargement and bulging of the face and jaws, thereby giving rise to the terms "big head" and "swelled-head" which are applied to it. The disease affects horses, mules and asses of all ages, classes, breeds, and of both sexes, but is probably more frequently observed in mature horses and Shetland ponies. The disease is found under all soil, food and climatic conditions."

The terms "osteoporosis" and "big-head" have also been used by A. W. Bitting[39], of the Florida Station, to apply to the same disease.

There is some confusion in literature regarding the application of the term "osteoporosis" for Mohr[34] uses it to apply to experimentally produced fragility of the bones caused by the administration of lactic acid or of foods containing no lime.

Hammarsten[40] referring to the experiments of E. Voit uses the term "osteoporosis" to apply to rachitic changes in bones of young animals, caused by lack of calcium salts in the food.

In this country we use "osteoporosis" to signify a definite disease, especially of horses, which is not caused by a lack of lime salts in the food. This use of the term is also so general elsewhere among veterinarians, that it should be restricted in its application to this communicable disease.

H. Ingle,[41] writing from Transvaal, reports analyses of the bones of horses, mules and asses which had suffered from osteoporosis. He found the ratio of nitrogen to ash to be 1:10.8 in bones of animals which had suffered from this disease and 1:14.37 in sound bones. The relation of phosphorus to calcium was the same in both cases.

Ingle considers that the cause of the disease is the low proportion of calcium to phosphorus in the oat-hay and Indian corn which compose the usual ration for these animals in Transvaal.

From Laws and Gilbert's analyses he concludes that the amounts of lime and phosphorus pentoxide in the ash of foods should be about equal. In the ash of South African oat-hay he finds the proportion of phosphorus pentoxide to lime to be as 100:51 and he quotes Wolff's analyses showing the proportion of phosphorus pentoxide to lime to be in Indian corn as 100:4.

Ingle also notes the fact that the ash of wheat bran contains phosphorus pentoxide and lime in proportion of 100:9 and considers its poverty in lime to be the cause of "bran rachitis," "bran disease" or "miller's horse rickets." The evidence, however, does not sustain Ingle's belief that deficiency of the forage in calcium is the primary cause of osteoporosis.

D. Hutcheon, Chief Veterinary Surgeon in Cape of Good Hope, whose abundant experience with osteomalacia in South Africa leaves him with the conviction that this disease is caused by deficiency of the food in bone-forming constituents, and who has found that it responds readily to medication with salts of calcium and phosphorus, insists that the osteoporosis of horses is an entirely distinct malady and that it is not caused primarily by deficiency of the food in calcium salts; further, he finds that it does not respond to treatment with bone-meal as does osteomalacia. It is apparently a communicable disease though the method and cause of infection are unknown.

Hutcheon distinguishes between the effects of these diseases upon the bones in part as follows:

"In osteomalacia the diseased bones retain their normal size and external appearance, but there is a softening of the walls of the bones, with slight enlargement of the medullary spaces, the marrow in which becomes highly vascular, and an increase in the cancellous tissue toward the ends of the long bones."

"In osteoporosis the affected bones are enlarged, their tissues soft and elastic and their honeycomb structure full of extravasated blood. The osseous tissue is pink, soft, easily cut with a knife, is spongy, elastic and yields blood upon pressure. The Haversian canals are greatly enlarged and filled with gelatinous exudate."

The most that can be said relative to remedial treatment is that a change of conditions and surroundings often affects a cure even in cases that have become severe.

THE HUMAN DIETARY.

This subject is of importance in human nutrition because of its bearing upon the matter of diet in diseased conditions and because of possible cumulative effects upon the development of the tissues through slightly abnormal conditions long sustained.

This generation of Americans, at least, feed themselves a superabundance of protein, especially in the form of meat. Meat does not contain enough mineral base to neutralize the mineral acids which may be produced from it in the body.

Vegetables and fruits are, because of their great excess of basic over acid mineral elements, much better suited to supplement meat than are the cereal preparations, none of which have any considerable preponderance of mineral base, while in most, the balance is in favor of mineral acid.

White bread has an excess of acid minerals and so have corn and most of our multitudinous, prepared breakfast foods.

This overconsumption of protein, especially in meat, coupled with our increasing use of cereal preparations and of sugar, which supplies carbohydrates without basic mineral matter, requires of us that we give attention to those foods which are by nature fitted to supplement this one-sided ration. Such foods are vegetables, especially, and also fruits.

We do not have definite evidence upon the strength of which to assert that a failure to consider this matter has led to the development of weak bones and poor teeth in human beings, but since the skeletons of other animals may be ruined by a very few weeks' feeding of these animals on meat alone or cereals alone, we must in fairness to ourselves consider it at least a possibility that wrong habits in the choice of food, especially for children, may in the course of the growing period unfavorably influence the development of the bones.

The liking for vegetables often requires to be cultivated in a child and not all children care for milk. Two such have come to the author's notice. Fortunately they are fond of fruit. Without fruit or vegetables or milk it would be difficult to satisfy a child with foods which provide a sufficient excess of mineral base over mineral acid, to insure the maximum growth of healthy bones.

It is easier and more comfortable to trust to instinct in these matters, but with our increasing independence in the choice of food, we must accept the burden imposed by our prosperity and learn rationally to shape our ways. Our interest in these matters is exactly similar to that of the traveller by foot who after having taken to an automobile, comes to have a new concern as to whether it is a field or a declivity over the hedge at the next turn of the road.

Where so many of the ills to which the flesh is heir are due to, or are influenced by, derangements of nutrition it seems that knowledge in this field should be a part of whatever system of living or education one may choose to follow.

Acidosis in infants. In infant feeding, acidosis is an exceedingly common source of trouble. The difficulty is most frequently met with in artificially fed infants.

Cow's milk supplies to the infant a greater amount of digestible protein in proportion to available alkali than human milk and hence the acids formed by oxidation of this protein will be greater in amount, relative to alkali available for their neutralization. This calls for ammonia to make good the deficiency.

Another factor in the causation of infantile acidosis is the high fat-content of cow's milk. Steinitz showed that the increased excretion of ammonium salts, on a milk diet rich in fat, was a consequence of the removal of alkali by way of the intestine. A part of the calcium, which normally would be excreted as calcium phosphate, forms a difficultly soluble calcium soap with fats of the food, and is then excreted in the feces. Either excess or indigestible character of the fat in the food may cause this increased elimination of alkalis in the feces, which, together with the consequent increased ammonia excretion by the kidneys, constitute the two most prominent indications of acidosis.

The use of skim milk, butter-milk, barley gruel, orange juice and egg albumen tend to alleviate symptoms of acidosis by virtue either of low fat-content or predominance of basic over acid mineral elements.

The limited capacity of young animals to tolerate fat in the food is a matter of common observation among stockmen. Cattle raisers commonly believe that calves thrive better on Shorthorn or Holstein milk than upon richer Jersey milk, and successful showmen commonly use as nurse cows, individuals of the breeds which yield milk relatively low in fat.

As bearing upon the feeding of infants we would call attention to the fact that selection has increased the fat-content of the Jersey cow's milk until even her own calf will thrive better on the milk of some other breed which yields milk that is not so rich in fat.

The writer once saw a thousand-pound Shorthorn steer calf which was being fitted for show, put onto a Jersey nurse cow which produced two pounds of butter-fat per day. For months the steer was a light eater and the slightest irregularity or change of food would throw him "off-feed." After the discontinuance of the services of his butter-producing foster-mother, he throve exceedingly. It is possible that acidosis is caused by such an excess of fat through its combination and excretion with calcium in the intestines.

Czerny and Steinitz[43] note that Keller in studying children suffering with gastro-intestinal complaints found in the urine almost invariably an abnormally high ammonia excretion, amounting to 52 percent of the total nitrogen, and that Van der Bergh gave sodium bicarbonate to infants suffering from digestive disturbances with the result that the ammonia excretion immediately decreased in a very marked manner.

Czerny and Steinitz conclude that this increased ammonia excretion in the urine of children suffering with digestive disturbances indicates the presence of acids and is formed for the purpose of their neutralization and not because of defective urea synthesis by the liver.

Czerny and Keller find that, among the various foodstuffs, fat alone leads to an increased excretion of ammonium salts in the urine.

Keller[44] finds that free acids are not excreted in the urine of children suffering with gastro-intestinal disorders but that they are eliminated in combination with ammonia.

Steinitz concluded that a diet of milk which was rich in fat might exercise an unfavorable influence upon the growth of children suffering from gastro-intestinal troubles through causing a loss of alkalis, which are essential to normal development.

Acidosis may also be caused in infants by too strict an adherence to a cereal diet. Steinitz and Weigert[45] report the composition of the body of a four-months-old child which died as a result of an exclusively cereal diet. The composition shows the body to have lost a large part of the sodium, potassium and chlorine normally present.

Czerny and Steinitz say, "The importance of relative acidosis in chronic disturbances of nutrition in infants lies in the loss of alkali.

For the growth and health of the child's organism the retention of alkali is as important as the retention of nitrogen, phosphorus, or other mineral substances. If it is withheld, or a loss takes place, the condition of the body can neither improve nor remain normal."

MINERAL BASES AND ACIDS IN FOODS.

For the sake of convenience in this discussion we use the term "ash" to signify a combustion residue in which all of the acid-producing mineral elements of the fresh substance are present. Unfortunately we have not access to any considerable number of analyses of foodstuffs which accurately indicate the amounts of the mineral elements contained, since almost all of the available determinations have been made upon the ash, which does not contain all or nearly all of the mineral matter of the fresh substance.

Sulphur especially is largely lost during ashing, even if this is carefully done. Other elements may also volatilize in this process. The loss is much more likely to decrease the total mineral acid present than the total mineral base and the loss is greatest in those products where mineral acids predominate.

Hence in order that the following figures may not mislead it is necessary to consider them as but most general indications of the truth, except where we know that adequate means were used for the estimation of the total amounts of the minerals present in the fresh substances.

The errors are quite misleading in the case of the cereals and cereal by-products. The excuse which we have to offer for using these analyses for a purpose which they serve so imperfectly is that they are the best available at this time; they do indicate some general truths of importance and their use for this purpose should serve to call the attention of other workers in the same field to the great desirability of making accurate mineral analyses of our foodstuffs. The amount of labor involved in such work is very considerable but we shall be able eventually to substitute more accurate figures for these which we have compiled.

In order to indicate what the loss in acid mineral elements in ashing may signify, let us examine the figures for gluten flour, No. 31 in the table on page 44.

In this foodstuff, Mr. A. C. Whittier of this laboratory, found 8.39 parts of ash per 1000 parts of dry substance, by an approved method involving the leaching of the charred substance. Sulphur was determined by fusion with sodium carbonate and sodium peroxide over an alcohol lamp and the amount of sulphur found was 10 parts per 1000; a greater quantity than was found of all the mineral elements together, in the ash.

MINERAL CONSTITUENTS OF VEGETABLE AND ANIMAL FOODS.—Parts per 1000 of Dry Substance.

		Moisture	Ash	Potassium	Sodium	Calcium	Magnesium	Phosphorus	Sulphur	Chlorine	C. C. Normal Solution, 1000 Grams				Authority for Analysis
											Total Base	Total Acid	Excess Base	Excess Acid	
1	Cow's milk	873 0	56 7	11.60	3.44	9 09	.88	6 50	.57	7 91	971.14	678.0	293 1	.....	K. II, 603
2	Woman's milk	876.0	24 2	6.79	1 65	2.88	.31	2.40	.18	4 45	414 11	291 6	122 5	.....	K. II, 598
3	Sow's milk	840.0	68.6	3.53	3.42	19.23	.74	11 13	.36	6 40	1258.40	921 1	337 3	.....	K. II, 602
4	Ewe's milk	855 0	69.0	13.95	2.30	15.34	59	9.10	.39	5 24	1269.6	759.2	510.4	.....	K. II, 602
5	Black Albumen	74.6	35.7	2.38	11.67	.41	.17	95	7.03	12 32	724.6	847.4	.....	122 8	Whittier
6	Beef	758 0	....	15.12	2 69	.08	.99	7.02	3.10	2 36	588.2	712 9	.....	124.7	Katz
7	Pork	729.0	.. .	9.37	5 76	.30	1.03	7.86	3 02	1.77	588 8	745 4	.....	156.7	Katz
8	Chicken	684 0	....	14.72	3 00	.35	1.17	8 01	3 70	1.90	619.7	801 2	... .	181.5	Katz
9	Eggs	734 0	34.8	5.55	4 53	2.10	.51	5.78	.13	4 85	484.9	517.8	... .	32 9	W. I, 158
10	White of egg	856.0	46 1	12 02	10.80	.92	.77	.89	.39	13.29	884 7	456 6	428.0	. ...	W. I, 158
11	Potatoes	750.0	37.9	18 90	.83	.72	1.13	2.79	.99	1 31	647 5	278 7	368 8	. ...	K. II, 898
12	Sweet Potatoes	700.0	30 7	12 82	1 49	2.18	.63	1.42	.68	3.91	552 6	244 3	308.2	.	K. II, 902
13	Beets, red	880.5	59.7	8.44	21.60	2.49	.11	2 56	.50	2 94	1285 9	279 3	1006 6	.....	W. I, 182
14	Turnips	868.0	80 1	30 20	5 85	6 07	1.79	4 45	3.59	4 06	1474.9	625 6	849.3	.....	W. I, 156
15	Tomatoes	962 0	260.5	82 50	32.93	11.36	13.57	10.73	4.98	18 05	5216.6	1512 1	3704 5	.....	A. & N., 236
16	Onions	865 0	52 8	10 98	1.25	8.29	1.68	3.46	1 16	1 46	886.1	336 8	549 3	... .	K. II, 919
17	Cabbage, heart	871 0	108 5	25.10	8.05	16.63	2 34	7 11	3 72	8 53	2011.9	931.4	1080.5	.....	M. & Von L., 1905
18	Asparagus	937 0	72 6	14.49	9.21	5.63	1.89	5 89	1 79	4 31	1205.6	613 3	592 4	.....	K. II, 924
19	Spinach	892 0	164.8	22.67	43.18	13 98	6.34	7 38	4.53	10.37	3670 2	1051 3	2618.9	.....	K. II, 929
20	Rhubarb	959 0	144 4	71 45	5 52	10 37	....	9 28	1.10	7.75	2581 7	886 0	1695 8	... .	W. II, 128
21	Oranges	843.0	30 8	9.31	3.08	5.40	1.50	1.49	.46	.72	763 9	145 1	618.8	.....	W. II, 124
22	Apples	840 0	14.4	4.27	2.79	.42	.76	.85	.35	....	313.5	76 7	236.8	.....	W. I, 126
23	Plums	786 0	20.8	11.98	.36	.60	.61	1 19	.20	.07	401 6	91 2	310 4	.....	K. II, 959
24	Raisins	261.0	28.6	11 05	1.57	1 09	.98	2.23	.69	1 39	585.2	226 9	259 1	.....	A. & N , 237
25	Figs	789 0	29.2	13.54	.52	2.27	.99	1.63	.46	.60	562 9	150 8	412.1	.....	K. II, 959
26	Apricots	842 0	42.1	21.95	3.35	.89	79	2.03	.43	.18	815 3	162 9	652.4	... .	K. II. 959
27	Wheat, grain	144.0	20 8	5 04	.26	.41	1.41	4 08	.09	.58	276 2	285 3		9.1	M. & Von L., 1905
28	Wheat bran	....	61 6	14.58	.30	1.27	6.22	13 54	.02	...	959 4	874 8	84 6	.....	W. II, 126
29	White bread	355.0	21.5	1.25	3.14	....	.29	1 58	1.25	6 53	192 0	364.1	....	172 2	A. & N., 227
30	Graham bread	412.0	26 6	3.21	2 86	1.03	.75	2.48	.22	6.41	319.0	354 5	....	35 5	A. & N., 229
31	Gluten flour	70 5	8.4	.47	.43	.90	.59	1.96	10 00	.38	123.6	200 0	....	75 9	Whittier
32	Rice, hulled	121 0	3.9	.70	.16	.09	.26	91	.01	.004	50.7	59 4	....	8 8	W. I, 154
33	Oat meal	98 0	18 3	3.61	.58	.97	.86	3.85	.05	.98	236.4	279 2	. ..	42.8	K. II, 834
34	Oats, grain	143.0	32 0	4 65	35	84	1 34	3 77	.23	.35	285.9	267.5	18.4	.....	M & Von L , 1905
35	Corn, grain	133 0	14 5	3 59	.12	.23	1.36	2.89	.05	.13	219 8	192.9	26.9	... .	K II, 775
36	Corn, grain	120 8	15 5	3 20	52	.11	1.25	3 36	1 60	45	212.3	329 3	...	117 0	Whittier
37	Corn bran	77.5	13 3	2.60	.00	.33	.82	1.24	.76	.42	150 3	139.3	11 1	.....	"
38	Pearl hominy	111 8	4 05	1.08	.12	.05	.21	.55	1 36	.54	52 1	135.6	..	83 4	"
39	Beans	140.0	36 3	12.50	.29	1.30	1 57	6 16	.49	.65	525 6	446.3	79 3	... .	K. II, 784
40	Soy beans	78 9	31 4	11 62	.23	1.19	1.69	5.06	34	.08	504 9	349.9	155 0	.....	W. II, 34
41	Cottonseed meal	.....	74.8	18.48	.....	2 36	6 86	15 01	.37	.03	1153 0	992.3	160 6	... .	W. II, 127
42	Linseed oilmeal	122 0	58.4	11.82	.68	3.50	5 51	8 06	.78	.46	963.3	581 6	381.7	... .	M. & Von L., 1905
43	Corn stover	150 0	53 3	16 02	.44	4 15	1.85	1 54	1.13	.94	787.2	196.4	590 8	... .	" " " "
44	Oat straw	143 0	70.8	13 57	1.73	3.59	1.62	1.53	93	4 67	733.7	288.4	445.3	.....	" " " "
45	Timothy hay	143 0	68.3	19 67	.95	3.92	1.34	3 51	.79	3 50	849.2	374 5	474 7	.....	" " " 1888
46	Red clover hay	160.0	68 6	18 38	.97	17 11	4.53	2 89	.90	2 62	1736 9	316 5	1420 4	... .	" " " 1905
47	Alfalfa hay	160.0	73 8	16 41	97	21 44	2.23	3 38	1 72	2 98	1713.7	409.4	1304 2	.....	" " " "
48	Rape, green	870.0	80.8	22.35	2 29	12.64	1.86	4 03	4.62	6.15	1453 4	721.7	731.7	.....	" " " "

NOTE: The above analyses represent edible portions only.

The analysis of corn, No. 35, from König, is as satisfactory as any we were able to find in literature. A comparison of these figures with those of A. C. Whittier for the same product, No. 36, gives further illustration of the loss of minerals in ashing.

Thus it is apparent that final judgment as to the balance between basic and acid mineral elements in cereals must be withheld until warranted by further analytical work.

The analyses in the table on page 44, followed by the initial "K" are from König's "Chemie der menschlichen Nahrungs-und Genussmittel;" those ascribed to Katz are from Arch. ges. Physiol., vol. 3, p. 14; those followed by the initial "W" are from Wolff's "Aschen Analysen," "A. & N." signifies Albu and Neuberg's "Mineralstoffwechsel," "M. & Von L.," Mentzel and Von Lengerke's landwirtschaftliche Kalender and those by A. C. Whittier are from this laboratory. In these last, the sulphur determinations were made by fusion of the fresh substance.

In this table on page 44, we state the amounts of the various mineral elements contained in 1000 parts of dry substance. In the third and fourth columns of figures from the right, we state the total amount of acid minerals and of basic minerals computed to normal solutions, that is, so that one cubic centimeter of acid will exactly neutralize one cubic centimeter of base. Phosphoric acid is considered to be neutralized when two of its hydrogen atoms are replaced by a base.

In the two columns on the right side of this table is stated the excess of acid or base, as the case may be, in cubic centimeters of normal solution in 1000 grams of dry substance. To reduce any of the figures to the fresh or air-dry basis, multiply the numbers as stated by the dry substance expressed as percent.

This excess of acid or base as stated in the table is obtained by subtracting the total amount of acid (phosphoric, sulphuric and hydrochloric) from the total amount of base, (sodium, potassium, calcium and magnesium.)

Thus we ascertain the nature of the active or unsatisfied excess of mineral matter, that is, whether it is base or acid. The rest is like a balanced account, debits equaling credits

The excess, if of alkali, may be considered to represent carbonates or organic compounds such as upon oxidation yield carbonates of alkalis (sodium or potassium) or of alkaline earths (calcium or magnesium); if of acid it may be considered to represent acid-reacting elements such as upon oxidation yield free mineral acids.

In spite of the wide range of variation which there is in the composition of the ash of organic substances, in accordance with differences in species or environment, a general agreement as to balance between acid and basic minerals in foodstuffs of the same class, is apparent.

From these figures it would appear that the ash of milk is markedly alkaline and from this it is probably safe to conclude that the food of animals should possess an excess of mineral bases in the ash. This assumption seems particularly justifiable when we consider the fact that on the basis of Lawes and Gilbert's work, mineral base predominates in the ash of animal bodies and further when we consider the probability as shown by Soxhlet[46] that the calcium content of milk constitutes the limiting factor in the production of growth and that the storage in growing animals is more largely of basic than of acid mineral elements.

Black albumen, No. 5 in the table, a packing-house by-product, is the first separation of serum from blood-clot in the preparation of the clear, dried serum used in dyeing. We use this black albumen as a low-phosphorus proteid in nutrition experiments. It is rich in sodium, magnesium, sulphur and chlorine and has an acid ash.

Beef, pork and chicken flesh all have acid ash and Sherman calls attention to the fact that carnivora make good the deficiency of mineral base in flesh by the consumption with it of parts of the bones. As an only food, flesh undoubtedly possesses an excess of acid mineral elements.

The white of egg has a strongly alkaline ash while the ash of eggs as a whole, without the shell, is slightly acid.

We should not argue, however, that because mineral acids slightly predominate over mineral bases in eggs, animal food should possess a like excess of acid, since the egg is not food in the sense in which milk is food. The egg is potentially a complete being in itself, merely requiring transformation into the more highly specialized tissues of the fully formed animal and maintenance during the process. There is neither the necessity nor the provision, as in milk, of adaptation to the processes and activities of the digestive tract of the animal to be nourished.

Fruits and vegetables have, without exception, strongly alkaline ash. Their natural acidity is due to organic acids which are oxidized in the body and excreted as carbon dioxide and water.

Beets, cabbage, rhubarb, spinach and tomatoes have exceedingly alkaline ash, the excess of alkali ranging from one cubic centimeter of normal solution in beets, to three and seven-tenths cubic centimeters per gram of dry substance in tomatoes.

Potatoes, onions and asparagus are also conspicuously basic as to ash, but in a class decidedly second to beets, cabbage, rhubarb, spinach and tomatoes.

Fruits also are unmistakably basic as to ash, apricots and oranges containing considerably more than half a cubic centimeter of excess normal base per gram of dry substance, while figs come a little under this mark and apples, plums and raisins are in a second class as regards alkalinity of the ash.

Of the cereals, wheat appears to be slightly acid, as are also white bread and graham bread, gluten flour, corn, pearl hominy and oat meal. Further work will doubtless show that the measure of acidity in most of these cases is low. Oats here appear to have an alkaline ash, doubtless due to loss of acid minerals; corn bran has a slightly alkaline ash and wheat bran is, on the basis of the evidence at hand, doubtful as to reaction of the ash. The cereals are usually considered to have an acid ash and as is well known, do not support normal growth of bone.

Magnus-Levy[6] says: "A part of the vegetable foods of man, the cereals, yield (just as does flesh) an acid ash, whereas the grasses and herbs of herbivora yield an alkaline ash. Cereals are equivalent to animal food in respect to the metabolism of the ash."

In corn there is a decided excess of acid minerals over basic minerals and the total ash of corn is also low. Both of these factors may contribute to the production of acidosis by corn, as also may the disproportionate excess of magnesium in comparison with the small amount of calcium present. As in corn, so in bran, the magnesium content is greatly in excess of the calcium, while, for structural purposes and for milk production, very much more calcium than magnesium is needed.

In spite of the richness of bran in mineral matter the existence of "bran disease" or "miller's horse rickets" indicates that its mineral nutrients are in a some way out of balance.

Mendel and Benedict[47] find that the injection into an animal of either calcium or magnesium salts, leads to an increased excretion of the other, (calcium if magnesium has been injected or the reverse), by the kidneys.

J. Malcom[48] comes to the conclusion that the ingestion of soluble magnesium salts causes a loss of calcium in adult animals and hinders its deposition in young, growing animals, but that soluble calcium salts do not in the same way affect the excretion of magnesium.

Beans, soja beans, linseed oilmeal and cottonseed meal are all high-proteid foods and their sulphur contents should be correspondingly high. The evidence hardly warrants drawing conclusions as to the balance of minerals in the ash of these foods.

The various hays and straws appear to have strongly alkaline ashes. Clover and alfalfa, however, largely because of very high lime contents, have much more alkaline ashes than have the grass plants.

While it is universally recognized that clover or alfalfa, with corn, constitutes a ration, for farm animals, which cannot be greatly improved, especially for the production of increase in weight, still it is not so generally understood that the high content of these legumes in mineral bases generally and calcium in particular, constitutes an important factor in the superiority of these feeds as supplements to corn. This, however, is undoubtedly true since these legumes are characteristically rich in those mineral nutrients which are lacking in corn.

A comparison of some of the above figures with recent work by Sherman and Sinclair[49] indicates that the estimates of the acid mineral elements of wheat, oatmeal and milk are probably decidedly low, though in each case the balance would remain on the same side of the account as indicated by the figures which we quote.

This balance between acid and base in foodstuffs may be modified, before these nutrients reach the tissues, by certain influences in the alimentary tract. Thus according to Albu and Neuberg[14] the amount of calcium absorbed from the intestine is influenced by the other salts present, sodium chloride increasing its resorption and alkalis diminishing it. The formation of difficultly digestible calcium soaps in the intestine may also alter the balance between the acids and bases resorbed. Further, variations in the solubility and resorbability of the salts in the various articles of the dietary tend to render definite conclusions difficult; and calcium from vegetable foods is much less completely absorbed than the calcium from flesh.

It is also impossible closely to estimate the proportion of the mineral bases that will leave the body in combination with organic acids in the urine. To be entirely accurate it would also be necessary that we leave out of consideration such portions of the organic sulphur and phosphorus of the food as leave the body in organic combination; also that we consider in a more definite way than is now practicable, such organic acids as leave the body in combination with mineral bases, and further that we consider the fact that some phosphorus leaves the body as acid phosphates, that is, without carrying with it enough inorganic base to render it neutral. There is, however, a compensating factor, since some phosphorus leaves the body carrying more than enough mineral base to render it neutral.

Is it a matter of importance whether this balance be maintained at a high or a low level? The excess of either acid or base might be the same in a food very poor in both as it is in one very rich in both.

In answering this question we must bear in mind the fact that excess of acid or base is but one of the many factors affecting the usefulness of the mineral elements as animal nutrients. All of those minerals which are of use in the body as neutral inorganic salts, might be withdrawn from a ration without altering in the slightest degree the excess of either acid or base. The great majority of the functions of the mineral elements in the body are served in accordance with the amounts and kinds of minerals present, and quite irrespective of any excess of bases or of acids, unless such excess interferes with normal processes. (See note.) Thus it appears that it is a matter of great importance that the balance be maintained at a high level rather than at a low one.

SUMMARY.

The organic acids of foodstuffs, such acids, for instance, as the citric, malic and tartaric acids of fruits, are mostly oxidized in the animal body to carbon dioxide and water, in which compounds they are excreted; but there are formed within the body, mineral acids which cannot be decomposed and eliminated in this way. These acids must be neutralized in order to protect the animal from a disturbance of conditions essential to the continuance of vital reactions.

These acids are formed chiefly by the cleavage and oxidation of the proteids, either of the body or of the food, the sulphur and phosphorus contained therein, as constituent parts, being oxidized to the corresponding inorganic acids.

These acids are neutralized,

(1) by carbonates of the food, water or tissues;
(2) by alkalis liberated by the oxidation of organic-acid salts;
(3) by ammonia withdrawn from the constructive formation of urea;
(4) by ammonia from the tissues;
(5) by ammonia splitoff from proteids, especially for acid-neutralization.

Both acid and base are also liberated in slight amounts by the decomposition of sodium chloride in the formation of gastric juice.

NOTE: For information relative to the amounts of the various mineral elements required by animals the reader is referred to Kellner's "Ernahrung der landwirtschaftlichen Nutztiere," to Von Noorden's "Metabolism and Practical Medicine" and to Bul. 201 of this Station.

The continued neutralization of excessive amounts of acids by some of these means, especially by use of the carbonates of the bones, may mould the whole style of development of a growing animal; may cause serious states of malnutrition and may act as contributory causes of a number of diseases of both Man and other animals.

In case the acids formed within the body or introduced into it exceed the animal's capacities to neutralize them, death may ensue with symptoms of asphyxia, or suffocation, due to disturbance of the equilibrium of salts of the blood plasma, upon which depends the capacity of the blood to carry carbon dioxide from the tissues to the lungs.

The practical bearing of the subject is on the feeding of such animals as are reared most largely on cereals, namely, swine and poultry; especially on the growth of the bones of animals; on acidosis in infants; and on the care of sufferers from rickets, osteomalacia, osteoporosis, bran disease and diabetes.

In this connection we consider especially the acid mineral elements, sulphur, phosphorus and chlorine ,and the basic mineral elements, sodium, potassium, magnesium and calcium.

The relative amounts of mineral acids and bases formed in the body may be greatly modified by a choice of foodstuffs.

Fruits, vegetables, roughage and milk have alkaline ash; meat, eggs, cereals and many cereal foods and by-products have acid ash.

Corn has an acid ash and is also particularly deficient, as a food, in calcium and also in total mineral content.

In straight corn-feeding we see the resultant of a complication of deficiencies; corn lacks protein as well as minerals. In the ash, both acids and bases are deficient but the bases considerably more so than the acids, so that as an only food, corn is characterized by an excess of acid mineral elements and this excess, together with the deficiency in the total amount of mineral matter present, limits the growth of the skeleton; but if the protein in the ration of the corn-fed animal is increased by the use of supplements, to such extent as will support maximum production of proteid increase, then both phosphorus and the mineral bases must be increased.

The basic mineral elements in a ration must be present in quantities corresponding to the protein, since the sulphur and phosphorus of the food proteins constitute the principal sources of mineral acids in the body.

It is important not only that there be a considerable excess of mineral bases in the food but also that this excess be maintained at a high level, that is, that aside from the balance between acid and base. the total quantity of ash should be considerable.

The capacity of the animal body to neutralize and eliminate alkali seems to be entirely adequate. In practice animals do not experience injurious excess of alkali as they do excess of acid.

Consumption of a needless amount of protein unnecessarily taxes the acid-neutralizing capacity of the animal and if carried to a sufficient extreme, results either in discouragement of the formation of bone or in malnutrition of the bones.

A high fat-content, or indigestible character of the fat of milk fed to infants suffering from digestive disturbances, causes acid intoxication by withdrawal of alkalis, by way of the feces, in the condition of difficultly soluble calcium soaps.

Because of the alkaline ash of the milk of all animals, it is assumed that other food of animals should have an alkaline ash.

Any such circumstances, as drought, or poverty of the soil in calcium and phosphorus, as tend to diminish the content of the forage in these elements, at the same time limits the growth of the bones and favors the development of diseased conditions in the animals consuming them.

No animals which consume fruits, vegetables, milk or roughage in sufficient proportion to other food are likely to suffer from an excess of mineral acids in the body. Animals fed too little else than meat, eggs, and cereal foods, including bread, are more likely than others to suffer from an excess of inorganic acids or a deficiency of inorganic bases.

Growing animals, when fed for protracted periods on either cereals or meat alone, suffer from malnutrition of the bones, this ailment being caused by the deficiency of these foods in mineral bases.

Swine, because of their very rapid growth, have especial need for calcium in the food, as is indicated by the unusual richness of sow's milk in calcium. Corn contains less calcium than other common grain foods and on that account is less perfectly adapted to serve as an only food for swine.

Clover and alfalfa are especially rich in calcium and hence serve to make good the deficiency of corn in this element.

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